NEXT MEETING, DECEMBER 18th, 1895.

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

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26 CORTLANDT STREET NEW YORK CITY.
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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, October 23rd, 1895.

The 100th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by Vice-President Francis B. Crocker, at 8 P. M.

THE CHAIRMAN:—[Vice-President Crocker.] Gentlemen, the Secretary has certain announcements to make in regard to routine matters.

THE SECRETARY:—At the meeting of the Council held at the office of the INSTITUTE this afternoon, the following associate members were elected:

Name.	Address.	Endorsed by
BYRNE, HARRY	Organizer, The National School of Electricity, Chicago, Ill.; residence, 5620 Drexel Ave.	C. C. Haskins. Harry H. Hornsby. Arthur Frantzen.
COLES, EDMUND P.	Special Tester, General Electric Co., Schenectady, N.Y.; residence, 240 Union St.	John B. Blood. Thorburn Reid. W. J. Davis, Jr.
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CRAWFORD, L. G.	Sup't, Repair Dep't Gen'l Electric Co., Chicago, Ill.	Frank H. Dorr. Clare F. Beames. Chas. P. Steinmetz.
SHONNARD, HAROLD W.	Designer and Foreman, The Electric Self-Playing Piano Co, 333 W. 36th St., New York City; residence, 23 W. 43 St., Bayonne, N. J.	T. D. Bunce. Frank Martin. Robt. Lundell.
WALKER, ARTHUR F.	Sup't and Electrical Engineer, Edison Light Co., Grand Rapids, Mich.	Frank B. Rae. Chas. Wirt. W. S. Barstow.

Total, 6.

THE CHAIRMAN:—I have to announce officially, what you all know personally, the fact that one of our most distinguished members and past officers was accidentally killed by the agency

which he was most familiar with, and that owing to the unavoidable absence of Dr. Duncan, who has interested himself in this matter, I am called upon to take the Chair. Dr. Duncan has very appropriately selected Mr. Thomas D. Lockwood to prepare and to present to you suitable resolutions in regard to the death of Franklin Leonard Pope, Past-President of the INSTITUTE. I will now call upon Mr. Lockwood to present these resolutions.

MR. LOCKWOOD:—Mr. Chairman: It seems to me exceedingly fitting that before proceeding with the regular order of business, the INSTITUTE, as a body, should recognize that its duty, albeit a melancholy one, is to consider the sad event you have announced, and to pay its sorrowful but sincere tribute of honor and affection to the memory of our lamented Past-President and distinguished fellow member, Franklin Leonard Pope.

We must all deplore very much that thus early in the season of 1895 and 1896, we are under the painful necessity of recording the loss of one whom we have known and respected for so long—and yet, alas, for so short a time. I have been honored with Mr. Pope's friendship for some twenty years, and for ten years before the beginning of that period, I knew of his name, reputation and abilities, and I had set before myself, his example, as one well worthy of emulation in the career I hope to achieve.

It does not appear to me that this is the proper time to recount biographically, his life-story and work, since I am well assured that that will be done for the archives of this INSTITUTE by hands more skilful, and by tongues more eloquent than mine; but I cannot refrain from briefly testifying for myself, as a private citizen, a brother in profession and a fellow member and associate in this INSTITUTE, to the high sentiments of regard and admiration which from the earliest moment of our several years of acquaintance I have entertained and cherished for Mr. Pope, and the heavy and crushing sense of personal loss which has weighed upon me since I first read the sad news. And yet, Mr. Chairman and gentlemen, I welcome the intensity of the personal loss of which I have spoken, because I feel and I am convinced, that by it I am enabled in some measure the more truly to sympathize with the incomparably deeper sorrow of his family and kindred.

The life of Franklin L. Pope, as we all know, was an essentially busy one. It was one of constant and unremitting toil. When I first heard of him I was but a boy and he was comparatively a young man; but even then he was in the forefront of the work, and he was chief of exploration for the Russian-American Telegraph, which the Western Union Telegraph Company at that time had in process of construction, under the belief that the transatlantic cable could never be successfully laid. His toil, however, differed from that of the majority of mankind, in that it was three-fold, for not only did he toil to acquire and accumulate knowledge, but he also toiled in the utilization of

knowledge, and furthermore, and I think this was better than all, he always toiled with the glad hope of imparting knowledge, and in all of these three varying methods he toiled to the end, and we can truly say, he veritably "died in the harness." We may well sorrow as a body that he was not spared to work longer or to more fully enjoy the fruitage and harvest of the seeds which he has ever labored to sow, and the young growth of which he ever labored to prosper.

Those of us who had the happiness of a close intimacy with Mr. Pope will bear me out when I say that we shall remember him always as showing the kindness and genial spirit of a true friend; as being one who reverenced the right; endeavoring always to do his duty as he saw it; and as possessing, in addition to marvelous ability in many directions, and great powers of generalization, analysis and expression, a large share of modesty, that inherent attribute of true genius and talent. Employing the words of the inspired writer, we then may truly say that "a prince and a great man" has been taken from us, and I am confident that every member of this INSTITUTE will regard it as a privilege to be associated with the expression of our sorrow and our sympathy with the bereaved family. With this confidence, Mr. Chairman, I have therefore a sad satisfaction in presenting resolutions which formulate such expression, and in moving their adoption by the INSTITUTE.

These resolutions are as follows:

Whereas, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has heard with heartfelt sorrow of the sudden death by a lamentable accident, of its Past-President, Franklin Leonard Pope; and

Whereas, we, the members, Council and officers of the INSTITUTE desire to express our profound realization of the bereavment we have sustained, and the sincere grief we experience, and to record in fitting terms our keen appreciation of the great worth and high qualities of our fellow member; his eminent services to our organization; and his able, unwearying and successful work in applying electrical energy to many useful purposes; it is therefore

Resolved, that by the death of Mr. Pope, called away in the full fruition of manhood and the meridian vigor of intellect, the profession at large has suffered an incalculable loss, and the INSTITUTE has been deprived of a most distinguished and valued member, and a wise and sagacious counsellor, endeared to many members by long, pleasant and affectionate intercourse, and esteemed and respected by all, no less for his kindly and warm-hearted nature and dignified simplicity of character, than for his universally acknowledged genius and great ability.

Resolved, that we hereby express the poignant grief wherewith we contemplate the sad event which has taken from us one who, whether in the earliest days of our Association, co-operating in its successful establishment, urbanely and efficiently presiding as our chief Executive Officer at business and social meetings, discreetly and judiciously performing the unassuming duties of a member of the Committee of Editing, or in the capacity of an individual member serving the interests of harmony and stability, has uniformly had the dignity of

the INSTITUTE at heart, and has assiduously, cheerfully, and faithfully labored for its welfare; and while we sincerely mourn the loss of an associate so eminent and useful, thus suddenly withdrawn from the activities of this present life, we more earnestly, grieve for the parting from a friend so sincere, faithful and true.

Resolved, that we extend to his stricken family our tenderest sympathy, in this, the hour of their affliction, and that in testimony thereof a copy of these resolutions be forwarded to them.

Resolved, that these resolutions be appended to the minutes of the council and be published in the TRANSACTIONS of the INSTITUTE.

The resolutions were unanimously adopted.

THE CHAIRMAN:—The regular business of the meeting is the reading of papers. The first paper is by Mr. Hermann Lemp, Jr., on the "Local Annealing of Hard Faced Armor Plates."

A paper presented at the one-hundredth Meeting of the American Institute of Electrical Engineers, New York and Chicago, October 23d, 1895.

LOCAL ANNEALING OF HARD FACED ARMOR PLATES.

BY HERMANN LEMP, JR.

Every one is now more or less familiar with the Thomson Electric Welding process, which in past years has been introduced in almost every metal industry, in one shape or another. This process created a new field in the technical application of currents of large volume and small E. M. F., a field which, while it was primarily intended for welding, naturally suggested a number of other applications to so fertile an inventor as Prof. Thomson; and so it happened that early in its fundamental inception, the use of large currents was contemplated to be utilized for heating plain metal bars or parts of sheet billets, etc., for forging purposes, to rivet, upset, to temper or withdraw the temper, or to be worked upon in any well-known manner while being kept heated by the current.

It has been the good fortune of the writer to lately work out one of these novel applications, and since the literature concerning this branch of electro-technics is somewhat limited, he has thought it advisable to bring an account of the same before the INSTITUTE.

One of the latest advances in the making of protective armor for battle-ships, or even forts, has been the introduction of what is known as the Harvey process. For those not conversant with the latter, I will briefly state that it consists in taking an ordinary low carbon steel plate and introducing an additional percentage of carbon into the surface metal, thus changing the crust to the depth of about an inch, into a steel resembling tool steel. A plate thus treated, is lastly water-hardened, similarly to an

ordinary tool, and by experience has shown to offer, under equal conditions, more resistance to the impact of a projectile than any other armor known, and therefore we will take this as an illustration of hard faced armor. The extreme hardness of the surface of a Harvey plate, while exceedingly valuable in preventing projectiles from piercing it, has a disadvantage when it is required to be pierced by a drill and tap. Such holes may be required either for fastening ladders, swivels or other appliances to the hull of the vessel, or to fasten T flanges supporting the deck to barbettes or turrets.

The methods heretofore used to produce these holes were principally two:

1. To protect the surface of the plate in patches or strips, to prevent carburation, wherever holes were expected to be drilled.

2. To make accurate drawings and patterns of each plate beforehand, to which all holes are drilled before plate is hardened.

Plan No. 1 was practiced in the United States until it had to be abandoned. In practice it was found that numerous alterations in construction, errors in either draughting-room or mills, made it necessary to pierce holes where no provisions for annealing were made. It also happened quite frequently, that the method for prevention of carburation did not always work satisfactorily, and while white paint indicated well enough where soft metal was expected, very often hard metal was actually found. Hence it was patent from the first that some process was needed to rectify errors of this kind. Experiments were then made with oxy-hydrogen blowpipe, or the electric arc, to anneal such spots as were required to be drilled, and numerous mechanical devices for drilling, with drills of every design and method of tempering, were tried, until it seemed that the case was without a remedy.

It was at this stage that the problem was referred to the Thomson Electric Welding Co. of Lynn, and experiments were immediately undertaken to solve it. The process and apparatus necessary to carry it out, all resulting from the experiments undertaken, will be described presently.

The second method, which is used in England, has the advantage over the first, that there is no difficulty in carrying it out, provided there are no alterations made, and no errors committed. The present method of construction seems to be, to make, beforehand, a complete *model* of the vessel to be built; then make

accurate drawings and full-size patterns of every plate, giving the exact location of every hole. These are then bored, tapped and countersunk to a depth of approximately $\frac{1}{8}''$ and of a much larger diameter, filled with clay, and then the plate as a whole is heated and hardened with water. (See Fig. 1.)

This method works apparently all right, although in spite of drawings and models, errors are made. There is no doubt, however, that it is a slow and very costly method of working, and would hardly ever be resorted to in the United States.

From the above it seems clear that there has existed a need for a process by means of which isolated spots, regardless of location, might be annealed so as to permit drilling and tapping.

If, by sending a current of large volume through any spot thus to be treated, the spot is brought to a temperature of approximately 1000° F., there can be no doubt that the temper has been withdrawn. Experiments carried out to that effect at once

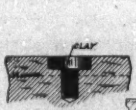

Fig. 1.

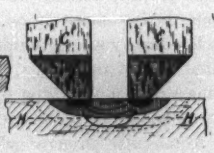

Fig. 2.

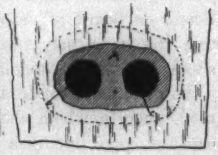

Fig. 3.

showed, however, that upon taking off the heating current the heat was so rapidly conducted away by the surrounding metal masses as to cause the heated spot to become chilled just as effectually as if it had been plunged into cold water. No method of outside protection of the heated spot would prevent this, and the *gradual* cooling of the spot had to be attained by different means: namely, a gradual and slow withdrawing of the heating current. The method of introducing the annealing current is best shown in Fig. 2.

c c are two copper contacts cooled by water circulating inside. The current enters the plate by one end, and leaves it by the other. Right under the contact, the metal comes to a bright cherry heat, (shown in black) while the portion intervening and partly surrounding the contacts acquires a temperature of just a visible red. Line h h indicates where the influence of the Harvey treatment stops.

The shaded portion in Fig. 2 and 3 shows the zone softened and ready to be machined, while the dotted line shows how far the heat radiation would cause the metal to turn blue. When cooled, the annealed portion shows a chocolate color, while the place where the contacts have been resting, is scaled and hard, and cannot be touched by a tool to a depth of about $\frac{1}{4}''$. These places can again be annealed later on, if required.

The apparatus necessary to carry out this process consists of the generator, the annealer proper (transformer) and the regulating apparatus.

The generator is commonly a separately excited alternator of variable potential, of a maximum of 300 volts and 100 amperes. The frequency, preferably, should be low, 50 cycles per second being used. When more than one annealer is to be run simultaneously from one generator, constant E. M. F. of the latter should be used, and each annealer regulated separately by a reactive coil. The annealer proper is a transformer similar to the well-known welding transformers. As the apparatus is to be operated outdoors, on board of vessels during construction, it is important that the same may be handled with immunity from electric shocks, even when operated in mist and rain.

To meet these conditions a copper-clad type of transformer is used, one in which the secondary is composed of two copper castings each having a rectangular groove, which two halves, when bolted together, form a closed rectangular frame in which the primary is held enclosed. The hollow space intervening between primary and secondary is moreover filled with a heavy oil, which acts both as the insulator and conductor of heat from primary to secondary. The secondary, by completely surrounding the primary, affords an excellent mechanical protection, and prevents electric as well as magnetic leakage. The primary is a copper ribbon insulated with asbestos, and the ratio of conversion is 100 to 1. The transformer has two trunnions fastened to its sides, in a line a little above the center of gravity, which trunnions swing in bearings, part of a yoke which straddles the whole. The yoke in its turn has a hook which may be secured to the latter at any place of the arch, thus allowing the transformer to be suspended, like a compass in gimbals, in any position desired.

It goes without saying that the copper castings which compose the secondary are cut through at one place in the circuit. On either side of the cut, two short platforms form the base for copper

contacts of various shapes and sizes, by means of which the currents are made to enter and leave the plate to be annealed. These copper contacts are of forged copper, hollowed out to receive water circulation for cooling purposes, and terminate in narrow tips rounded at the end.

The weight of the whole annealer, being approximately 1000 pounds, is sufficient to give proper contact pressure for all work on a horizontal plate. When inclined surfaces, vertical or otherwise, are to be worked upon, the transformer is suspended so that

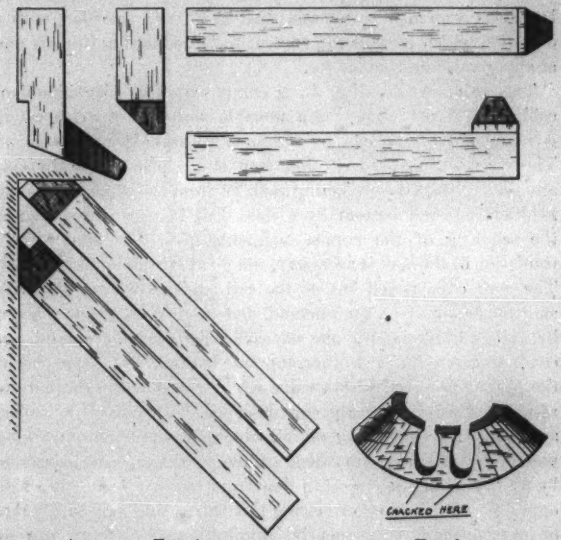

FIG. 4.

FIG. 9.

its weight shall not interfere with the contact pressure, which is obtained for work by bracing the contacts directly with wooden wedges against any object near by. On the outside of a hull, it is proposed to use a pair of electro-magnets, which are made to hold themselves against the iron hull, and form a support for the annealer. Fig. 4 shows some of the various shapes of contacts that are used in various positions.

The remarkable thing is the great amount of current that is

being carried by the copper contacts into the plate. The contact surface is seldom more than about $\frac{1}{2}''$ square, and yet 10,000 amperes are made to flow through it continually. This is equivalent to 40,000 amperes per square inch, a density which is only possible on account of the thorough cooling by the water circulation.

The regulating apparatus is in most cases simply a rheostat in series with the field of the generator. When more annealers than one are run simultaneously from one generator, as mentioned before, a reactive coil is interposed between the two, and this latter has been made automatic; that is to say, provided with a dash-pot, which permits the current to be reduced uniformly and at any given rate it is set for.

This reactive coil, Fig. 5., is composed of a solenoid coil of cable, well insulated, having a movable laminated iron core which is raised out of the coil by means of a leather strap and winch. The core is composed of thin iron strips placed side by side around a circle, and projecting radially from the same, and being held on top and bottom by a slate disk, in a manner similar to the securing of the copper segments of a commutator. No insulation of the core is necessary, and good ventilation is obtained. The core once raised out of the coil tends to return by gravity and the attraction of the solenoid, but is checked in its descent by a pair of dash-pots, one on each side of coil. These latter communicate with each other, top and bottom, and have one of the pistons provided with a valve which opens when the core is raised, and closes when the core descends. The dash-pot cylinders are filled with a light mineral oil, which does not freeze nor clog under any ordinary conditions of temperature. An adjustable by-pass valve allows the oil to flow from the tube to the top side opposite. By opening or closing this valve more or less, any rate of descent and, consequently, diminution of current, can be uniformly obtained, without requiring any skill on the part of the operator.

The annealing operation is carried out as follows: The transformer is placed in position, the contacts touching the plate either side of the place marked to be annealed, and the primary current brought up by means of a rheostat to from 75 amperes to 90 amperes for about two minutes, according to the size of spot to be annealed, which will bring the metal to a dull red heat, a temperature at which a pine stick catches fire when held in

contact with the plate. If no reactive coil is used, the current is now diminished by turning the rheostat one point every minute. If the reactive coil is used, the core is now raised by winch, the coil put in circuit by opening a short-circuiting switch, and then

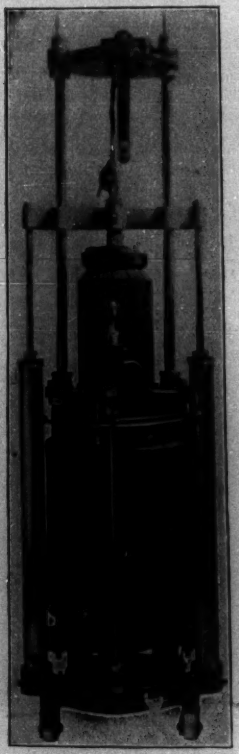

FIG. 5.

FIG. 6.

FIG. 7.

is allowed to descend on its own account. The operation generally takes *seven minutes*, all told. Accompanying Figs. 6, 7 and 8 show the proper apparatus in operation on the "Massachusettes" and "Oregon." No difficulty has been experienced

from the beginning. The annealing of individual spots was, however, only the stepping-stone to a more important work of a similar nature, work which was about to be given up, owing to what were considered insurmountable difficulties.

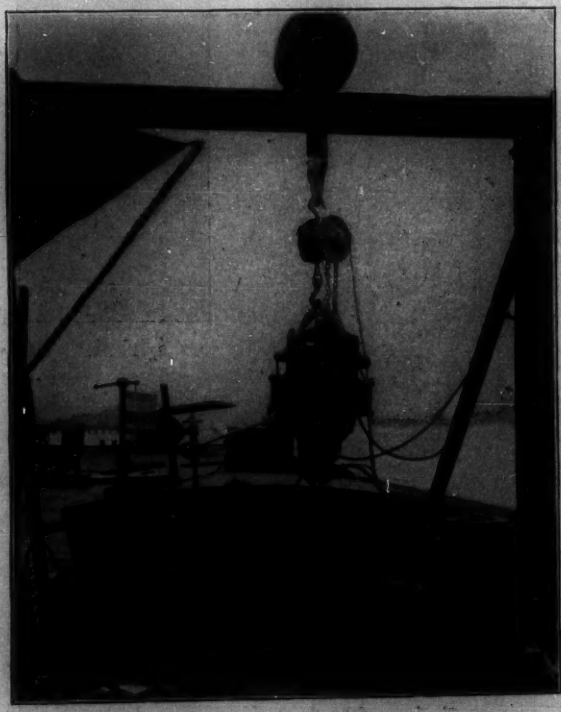

FIG. 8.

In the construction of a modern man-of-war, there are many armor plates which act as shields to the guns, and have to be perforated to allow the gun muzzle to pass through and to be either raised or lowered. Some of these shields are circular or

oval, with narrow edges around the ports, in the case of Harveyed plate. To perforate these shields after carburation, and before being water-hardened, was the only possible way, since previous experiments had shown that prevention of carburation could not be relied on, and no process was known to anneal the plate locally after hardening. The hardening of a plate once perforated, showed itself to be, however, almost impossible; in fact, a matter of chance. In most cases the plate cracked in two as shown in Fig. 9, or the whole plate became distorted in such a way that it could not be used. As individual spots

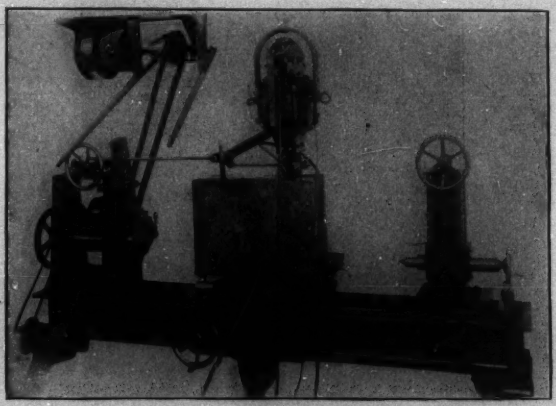

Fig. 10.

for holes could be annealed, there could be no doubt that a series of annealed spots could be likewise obtained by the electric process, following a line along which a cutting tool was expected to be run. The first attempt, therefore, and made in England, was to anneal a number of spots in proximity to each other in such a way that the annealed zones should overlap each other.

As described above, it is very important that the temperature of any individual part should be gradually and slowly withdrawn; and while for individual spots the only possible way to do this was by gradually diminishing the current, it was obvious that when a line was to be annealed, instead of annealing a number of spots side by side, the same effect of withdrawing the heat

gradually from one portion could be obtained by moving the apparatus itself relatively to the plate to be treated. The rate of this movement, of course, depended upon the rate at which the temperature should be allowed to fall in any particular spot to prevent chilling. The apparatus was therefore arranged to be moved along a line to be annealed, the motion being obtained by an ordinary screw and nut held in a bracket, the nut being turned at a predetermined rate controlled by a watch. It was found that a speed of about $\frac{1}{4}''$ per minute was sufficiently slow to ensure thorough annealing.

FIG. 11.

The copper contacts were of the simplest kind, as described above, bedding themselves partially in the surface, and when being dragged along by the screw and nut, raised in front of themselves a burr or chip similar to a planing tool. After a whole day's continuous use the copper contacts were found intact, while a number of chips from the steel surface were lying about. We thus had the peculiar phenomenon of a hard steel chip cut with a copper tool.

Upon the completion of the work, it was found that a strip about $2\frac{1}{4}''$ wide throughout the length over which the machine

had been moved, could be operated upon by drills or a shaper, in a manner as easily as if it had never been hardened before.

In the work just described, the apparatus was moved about, but in regular practice it would be better to construct a machine consisting of a large bed, on which the plate to be treated may be fastened and moved in any direction automatically at a predetermined speed, while the annealer proper is suspended in a given position above the plate, as shown in Fig. 10. The annealing operation occupies but a small percentage of the time required for the cutting.

Fig. 11 gives a view of a sample plate annealed by the method described above, and cut out to represent a port-hole as is used on the turrets of a man-of-war.

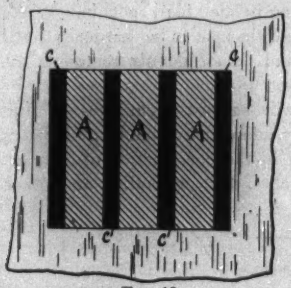

FIG. 12.

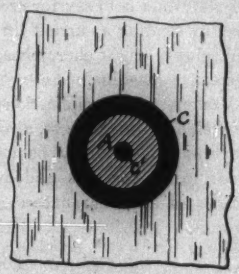

FIG. 13.

It is unnecessary to state that when the apparatus is used for continuous annealing, the primary current is kept at a nearly constant value, the diminishing of heat at any individual spot being obtained solely by the moving of the apparatus from it.

As mentioned before, the places where the contacts are passing over the plate, being brought to a higher temperature than any other, remain hard. Experience has demonstrated, however, that they may be re-annealed later on, by treating the spots in the same way as any other hard spot on the plate. By this means we are therefore able to anneal any shaped portions, not merely lines. This is best seen in Fig. 12, in which a series of strips are annealed side by side (shown in shaded lines A.) The hard faced surface is then removed on such places by a planer and drill; the machine is then run a second time over the annealed strips, rest-

ing it this time on the bottom of the groove and on the softer metal, thus annealing the ridges c left between the annealed strips, on which ridges the contacts were running previously. When all these strips are annealed they may be removed by machine tools without any further difficulty. In a similar manner a large round place may be annealed, as shown by Fig. 13. The transformer is set on the plate, one contact resting on c′, the other at any other place in circle c; the apparatus is then slowly revolved around contact c′ as a center, until the second contact has completed the circle c. The shaded portion A represents now the annealed surface, which is removed by a cutting tool. The contacts are then made to rest on either side of the center c′, and the latter is annealed and removed in its turn.

The apparatus may also be used for the reversal of the annealing process; that is to say for creating isolated hard spots in soft tool steel by sending a current through the spot to be hardened until it reaches a bright cherry heat, and then suddenly removing the current or machine.

Various other applications will suggest themselves in the operation of this process, already adopted by the United States Government. It may be used in the construction of burglar-proof safes, for dies and punches, for projectiles, and other articles of a similar nature.

Discussion.

The Chairman:—This paper embodies one of those novel applications of electrical energy in which it is perhaps our function to interest ourselves even more than in the established uses. It is these very new applications which deserve special recognition.

The point which strikes me is that Mr. Lemp is enabled to pass 40,000 amperes per square inch through a contact, of course cooled by means of water; but the mere fact that it is possible to pass such an enormous current density through a contact is certainly interesting, and I should imagine might be very useful in certain cases.

It is also interesting to observe that a current is produced in the secondary of the transformer, and that this illustrates the flexibility of electrical applications—that a secondary which consists merely of a ring of metal with an opening in it, so to speak, is employed to produce the necessary current.

This interesting subject is open to discussion.

Mr. Edward P. Thompson:—While I was listening to the paper, I wondered whether it would refer to the applicability

of the process to the opening of safes, and I noticed that it is alluded to in the last paragraph. I remember where a bank, only a few years ago, had paid thousands of dollars to have a burglar-proof safe put in. When they came to change the bank building, the safe manufacturer wanted them to put in a new safe. The President argued with him and said "That is a good safe; what is the matter with that?" "You see" was the answer "those doors don't come together with sufficient closeness, there is a crevice there which forms a basis upon which to use dynamite." So remembering that, I would be glad to hear what Mr. Lemp has to say as to those challenges that the manufacturers of safes offer. "There is a safe that it is absolutely impossible for anybody to break open," says the manufacturer, and it seems to me that Mr. Lemp could take one of his annealers and soften the surface to a sufficient depth to drill, and to introduce dynamite.

MR. A. E. KENNELLY:—I would very much like to ask Mr. Lemp if he can give us any figures as to the resistance offered by those two contacts. They are contacts of very limited area, are very hot, and the iron between them is very hot. If he would tell us how much pressure he uses in the secondary circuit of the transformer, and what the resistance of that portion of the circuit is, I think the information would be very useful.

THE CHAIRMAN:—I think it might be well to answer the questions as they present themselves, Mr. Lemp.

MR. LEMP:—In answer to Mr. Thompson, in reference to the opening of safes for the introduction of dynamite, I think it would be rather a hard thing to carry a transformer weighing 1000 lbs. to a place in the night (laughter), still if it is simply wanted to prove to the manufacturers of safes that a hole can be made through their plate if the latter is obtained by using tool steel, water hardened, there is no reason why it cannot be annealed by this method and drilled through with an ordinary drill; if, however, a different substance is used which does not allow annealing through heat, the process would be of no value.

In answer to Mr. Kennelly, I have never measured that resistance. I would say the weight of the apparatus, a thousand pounds, is sufficient to ensure contact, to pass the current through. As shown by the illustration in Figs. 2 and 3, the portion in black shows the metal raised to the temperature of a white heat, owing to the crowded state of current at that point. Of course, the copper contacts themselves are cooled by water, but the steel you cannot cool except through the medium of the copper contacts, and that is not sufficient. Still, if the contacts, to start with, are made pointed, there is no difficulty about passing the current through. They bed themselves right in the metal. If they are made exactly flat and ground, there would be lots of sparking but no contact, probably because the contact pressure is not sufficient in that case, when relying solely on the weight of the apparatus.

MR. KENNELLY:—The electromotive force in the secondary is how much?

MR. LEMP:—About two volts. It can be raised to three volts.

THE CHAIRMAN:—That would give the necessary data, would it not, if the resistance of the secondary circuit were known?

MR. LEMP:—The current, again, has never been measured; it has simply been computed from the primary current. We are passing 100 amperes through the primary circuit and the E. M. F. is about two.

THE CHAIRMAN:—The data are contained in the circuit, provided of course, the values of current, etc., are reasonable, and the resistance of the secondary is known. Is the resistance of the secondary measured or measurable?

MR. LEMP:—It is measurable, yes, I have never measured it.

THE CHAIRMAN:—I presume, compared with the contact of resistance, it is small.

MR. LEMP:—It is very small.

MR. F. A. PATTISON:—I would like to ask Mr. Lemp, whether he has ever compared the surface contacts when the terminals are pointed and when they are flat, and in that case whether when they are pointed the surface contact is very much larger than in the other case.

MR. LEMP:—The contact proper is never much more than half an inch square. To start with it is merely a point, and the heat immediately raises the surface of the iron into contact with the copper—a little hill forms itself, so to speak. The flat contacts were not so satisfactory for the reason that the pressure could not distribute itself evenly when only the weight of the transformer was used for obtaining the contact, and for this reason they were abandoned.

DR. EMERY:—What are the dimensions of those copper points there?

MR. LEMP:—The tips themselves are not more than one inch square. The copper contact itself is three inches square; by that I mean what we commonly call the contact—the whole piece of copper which is secured to the transformer; but that part which touches the armor plate and which really is the contact proper, is not more than one inch square, and being rounded, the contact surface is not more than approximately half an inch square.

DR. EMERY:—Is it rounded globularly or cylindrically?

MR. LEMP:—It is a segment of a ball.

MR. W. W. KER:—I would like to ask regarding the amount of space heated, when about 75 amperes are used, and also when you increase this current to say 10,000 amperes, what is the distance between the contact points.

MR. LEMP:—Seventy-five amperes are used when the hole to be annealed is not more than about $1\frac{1}{4}''$. When the full dimension is used like $2\frac{1}{4}''$ then the current is increased to from 90 to 100 amperes. Of course one thing to be considered is, that this being an alternating current, and passing through a large iron

plate, the energy actually employed cannot be computed from the current and E. M. F. It is considerably less where 90 amperes are used, the energy measured by a wattmeter is about 16,000 watts.

MR. E. P. THOMPSON:—Is the metal immediately surrounding the hole that is made, injured by its being annealed? Say that you anneal a certain portion in order to be enabled to drill the hole, I suppose it is impossible to anneal only just that portion of area equal to the whole. Therefore there would be some soft metal immediately around.

MR. LEMP:—The zone of annealing is somewhat larger than the place actually required; in other words, surrounding each contact there is a little zone of annealed steel. Right under the contact the metal is somewhat blistered and remains hard to a depth of about a quarter of an inch. Below this depth it is soft again. No injurious effect has been found in the iron.

DR. EMERY:—I would like to ask, if the contacts harden the metal, how the points where the contacts were first located can be annealed, without making other hard spots. Excuse me; in formulating my question I realize that the points do not harden the metal, but, being cool, they simply prevent the plate from being heated, so if they are moved to a place already annealed, they will not harden it.

MR. NELSON W. PERRY:—In the Harvey process, I understand the process is very similar to what is known as the cementation process in the manufacture of crucible steel, only in that case they use a wrought iron bar, and pack it in carbon and raise it to a high temperature, and hold it to that temperature for a sufficient length of time, and through a sort of endosmotic action, the carbon is absorbed by the surface of the bar and it is made exceedingly hard. In the Harvey process, I understand that they start with a mild steel and introduce additional carbon on the surface. Now there is another process in metallurgy by which they take a high carbon substance, such as gray cast iron, and pack it, not in carbon, but in an oxidizing substance, such as the oxide of iron and bring it to a high temperature. It has reverse action—it takes the carbon out and reducing its quantity, makes it malleable again. That is in general the process which is known as the malleable cast iron or cast steel process. From Dr. Emery's question it occurred to me that in case it was desirable to permanently take the high temper out of these hard spots after annealing, that they might interpose an oxidizing substance between the surfaces of the contact and the steel, so as to draw out a certain portion of the carbon and make it a lower carbon steel.

MR. TOWNSEND WOLCOTT:—I scarcely think that would work in seven minutes. The malleable iron process takes a good many days.

MR. PERRY:—That is because the temperature is very low.

But go into a foundry whenever a cast is made, and you will notice those blue flames, which are due to this very process taking place very rapidly, the oxidizing substance in this case being atmospheric oxygen. The rapidity of carburation or decarburation is some function of the temperature, and with that of the electric arc would be very rapid. I see no reason why the decarburation of a thin superficial layer under the conditions named might not be sufficiently rapid for practical purposes.

DR. EMERY:—Mr. Chairman: The answer to my question occurred to me as I asked it. I attempted to explain that the points do not harden the metal; being cooled they simply prevent annealing, and if placed on an annealed part of the plate it will remain soft.

[COMMUNICATION SUBMITTED BY MR. LEMP AFTER ADJOURNMENT.]

To answer more completely the questions put by Mr. Kennelly and Dr. Crocker, in reference to the contact resistance between the electrodes and the armor plate, I have made on my return to Lynn the following experiment:

The transformer was set upon a block of 18″ Harvey plate, with a distance between the tips of contacts of 2¼″, and a current of 90 amperes allowed to pass through the primary for approximately half an hour.

Inasmuch as the resistance of the contacts to be measured, causes considerable heating of the contacts, and this heat is carried away by the water cooling, this water cooling was made the means for determining the approximate resistance of the contacts. The water which was allowed to circulate through the contacts, was carefully measured for temperature before it entered, and when it left; and in this manner thermal units determined, which were lost through the contact resistance.

While it is true that not all the heat is properly attributable to the contact proper, and some of it is to be charged to the radiation from the heated surface, still this item is nearly enough balanced by the loss of heat of the contacts proper. The energy put into heating the water will therefore be a fairly good estimate of the heat caused by the contact.

The following data were obtained:

Current in primary.....90 amperes.
E. M. F. " " .....200 volts.
Energy as measured by wattmeter....15,698 watts:

8.4 lbs. of water passing through the contacts per minute were raised from 17° to 33°. From the above, total thermal units, 241.9, or a loss of 5.7 H. P. in both contacts. This was equivalent to 4352 watts for both contacts, or 2176 for one, and the current passing through the secondary being 9000 amperes, the resistance of one of the contacts is equal to .000026 ohms.

After the completion of the experiment, contacts were carefully inspected, and it was found that a circle of approximately $\frac{1}{4}''$ had been in actual contact with the armor plate, which with the current density of 9000 amperes would give a density of 19550 amperes per square inch. While this is not as dense as intimated in my paper, it represents the normal condition, whereas 40000 is a condition which occasionally happens, without however any injurious effects.

THE CHAIRMAN:—Is there any further discussion or are there any more questions to be asked in reference to this paper. If not we will proceed to the consideration of the next paper on the programme, "The Rating and Behavior of Fuse Wires" by Professor Stine, Mr. Gaytes and Mr. Freeman of Chicago. This paper having been sent to the members in advance it will only be necessary for the Secretary to call attention to certain of its points, that being the advantage of issuing papers previous to the meeting.

A paper presented at the One hundredth Meeting of the American Institute of Electrical Engineers, New York and Chicago, October 23d, 1895.

THE RATING AND BEHAVIOR OF FUSE WIRES.

BY W. M. STINE, H. E. GAYTES, AND C. E. FREEMAN.

It is with a certain feeling of hesitation that the attention of the general engineering profession is again called to a series of investigations relating to the well-worn subject of fuse-wires. Within the past few years a number of able papers on the subject by Messrs. Jackson and Ochsner, Mr. C. P. Matthews, and others, have been presented to the INSTITUTE. These have ably supplemented the work of Preece and other foreign investigators, and at the same time developed some points hitherto neglected. The latest contributor to this subject has been Mr. W. E. Harrington, who employed the circuit-breaker in his tests. The literature of the subject has been further increased by several excellent theses emanating from our leading technical schools. The bibliography, too, of this subject, has already been referred to in the TRANSACTIONS of the INSTITUTE.

However, the thermal cut-out is still one of the most unreliable of the many devices employed on electric circuits. Its use is universal, but beyond a few practical details the device is but little understood. The blocks in which they are used show some slow improvement, but most of this has been due to the vigilance of insurance boards, and they are still far from perfect. As a source of vexation and uncertainty, the fuse is probably unrivaled.

An analysis of the literature of the subject shows that the theory of the thermal cut-out has been thoroughly investigated. The elements entering its action have been carefully studied and incorporated into fairly satisfactory equations. Yet all tests and treatments have shown the thermal cut-out to be subject to such variations and modifying influences that but

little of practical value can be deduced from analytical investigations.

These considerations led the writers to attempt further investigations. The fuse was dealt with as an auxiliary to electrical circuits, and its behavior under such conditions was carefully studied. The work in great part bears on points already treated of, but it was considered best to study the entire subject afresh, and endeavor to present a more or less complete discussion of the behavior of some of the ordinary alloys employed in practice. Naturally, the data obtained has been voluminous, in all some 1300 determinations; but great care has been taken to thoroughly check all results.

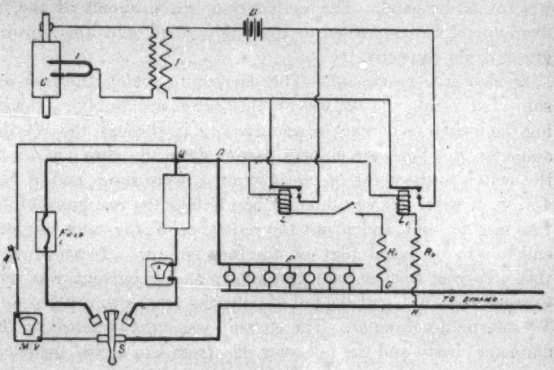

FIG. 1.

The Apparatus.—Fig. 1 is a plan drawing of the main and auxiliary apparatus, with all connections indicated. One of the dynamo leads was brought to the switch S. This switch was especially designed and constructed for these tests. The pivot was placed well toward the handle to make the travel of the blade as rapid as possible. The carbon rheostat, C. R., was built up of carbon plates, whose contact resistance was readily varied by screw pressure. The fuse was tested in a large box lined with asbestos, and open at the top, permitting of inspection and access, while at the same time protecting the fuse from draughts. The lamp rack, P, held 100 16-C. P. 110-volt incandescent lamps. These were connected in groups to switches, which enabled any

combination from 1 to 100 to be used. A step-by-step rheostat in multiple with this rack was used to adjust the current through the interval of one lamp.[1] By its use the current could be accurately adjusted within the limits of .4 and 60 amperes. For higher currents several similar racks were placed in multiple: L_1 and L_2 were small "pony" relays of 20 ohms resistance, having in series with each, five 16-c. p. 110-volt lamps, (R_1 and R_2) These relays worked on a current of about 10 milliamperes each, and were wired to close the circuit through the primary of the induction coil I. Two storage cells furnished the current for these relay circuits. T was an electro-magnetic tuning-fork driven by an independent storage-cell; C an iron chronograph drum which was turned by hand. The secondary or spark circuit of the induction coil was connected to the tuning-fork and the chronograph drum respectively.

Method of Experiment.—The current to which the fuse was subjected during the test was first measured accurately by throwing the switch on contact O, and passing it through the Weston ammeter, A. Both the circuits passing from the jaws O and N of the switch to the point of conjunction Q, were short, and of No. 4 A. W. G. wire. It was thought best to take the resistance of the fuse into account, and adjust the resistance of the ammeter circuit to exactly equal that of the fuse circuit. To accomplish this, a current smaller than the known fusing current was sent through the fuse, and the fall of potential from S to Q noted on a Weston milli-voltmeter. The current was next switched on the ammeter circuit and the fall over this from S to Q, was made exactly that over the fuse circuit, by adjusting the compensating carbon rheostat. The fusing current being accurately measured was switched over on the fuse. The fusing time was thus accurately ascertained. The lamp rack being a non-inductive resistance, the time interval for the current to rise to its full value on the fuse is negligible for all but the very shortest periods. The resistance of the bank of incandescent lamps could not materially alter during the quick throw of the switch, which was thrown by striking it a blow on the handle. Frequent observations made on the lamps did not reveal even the slightest tremor of the light when the switch was thrown. To render the point more certain, the time interval between the break and make of the switch was accurately determined chronographically, and found

1. For illustrated description of this lamp-rack see *Electrical Review*, New York, October 24, 1894, p. 201.

to vary between $\frac{1}{100}$ and $\frac{1}{1000}$ of a second. The fusing times were noted on a stop watch for all periods exceeding one second. For shorter periods the chronograph arrangement was used. The tracings of the electro-magnetically driven tuning-fork T, were made on smoked paper fastened over the drum C. This fork was always rated before each set of experiments by switching it in circuit with a standard second clock. Its rate was about 67 double vibrations per second. By frequent timing, all changes in rate due to temperature, etc., were noted and allowed for. The amplitude of the fork was large enough to allow periods of less than $\frac{1}{1000}$ second to be accurately measured. The records on the drum were made by sparks from the induction coil upon the breaking of one of the relay circuits.

The action of the relays was as follows:—When the switch was on O, L_1, was closed and L_2 open; when the contact was broken at O, L_1, opened, throwing a spark on the drum, and L_2 closed. The switch making contact at N, L_1 closed and L_2 opened, making the second spark record. When the fuse blew, L_1 opened, causing the third spark record. Though both relays acted synchronously, there was an interval during which the current through coil I was completely broken. Two distinct records were made in every case. The interval between the first and second sparks gave the period of open circuit for the switch, while the interval for the second and third sparks gave the fusing times. The relay circuits are indicated with sufficient clearness on the diagram.

The Experiments.—As our experiments were designed to exhibit the behavior and characteristics of the fuse used for protecting electrical circuits, it was considered best to adopt not more than two brands of wire for all the tests, rather than employ a large number of varieties. Other investigations have shown that the various makes of fuse wire closely resemble each other in behavior, and the conclusions obtained with one wire would be general for all. The first make of wire was purchased from supply houses, the second was furnished by the manufacturers.

First Series.—These tests were made under conditions which we shall call commercial, or those which obtain in practice. In all cases the fuse wire was carefully inserted, so as to obtain a uniform pressure of the wire under the screw head without unduly crushing it. The same block was used repeatedly, and little care taken to keep the terminals clean. This was done to more nearly imitate practical conditions. In only two or three cases

out of hundreds of fuses blown did the rupture occur at the contact. Two classes of porcelain cut-outs were employed; one was the open porcelain base "main line" style, the other the closed porcelain "K. W." variety. In the latter, the 10-ampere size has a space of only ½ inch between its terminals, though the fuse is suspended out of contact with the porcelain base. This style of block has recently been condemned by the underwriters, and very properly. With the terminals so close together, a fuse blowing at 20 amperes invariably establishes a vicious arc, and the terminals melt with such explosive violence as to frequently shatter the block. Though the open type of block has an added fire risk, the terminals are, as a rule, further apart. A pronounced fault in their construction is that the terminals are let in flush with the surface of the porcelain. Nearly all types

TABLE I.

FUSING CURRENTS IN AMPERES.—LIMITING TIME 1 MINUTE.

	A ½ Amp.	A 1 Amp.	A 2 Amp.	A 3 Amp.	A 5 Amp.	A 10 Amp.	A 25 Amp.	B 4 Amp.	B 8 Amp.	B 12 Amp.
Covered Block, ½ inch ...	2.5	5	10	14	20	35	—	13	—	—
Open Block, ½ inch	3	5	9	10	15	25	—	—	—	—
Open Block, 1 7-16 inches.	—	—	—	—	—	—	30	—	—	—
Open Block, 8 inches Vert.	1.5	3	5	6	9	14	20	—	7.5	10
Open Block, 8 inches Hor.	2	4	6	7	11	—	20	—	—	—

of porcelain fuse-blocks merit severe criticism on several points. The terminals are too close together in small sizes, the fuse often resting on the top or base; and their mechanical construction is very poor. Too little attention seems to be given to the proper function of a fuse-block in its design.

Table I needs but little comment. It clearly shows the unreliability of the porcelain fuse blocks used, and also the imperfect commercial rating of the fuse wire, A. The limit of fusing time was 60 seconds. Fuses larger than five amperes will often blow in from one to three minutes on a current somewhat less than stated, but this correction is so slight for these results that it need not be seriously considered.

Second Series.—The open eight inch block was adopted to avoid all cooling effects from the terminals. When used horizontally, the fuse rested on a number of thin asbestos supports

let into grooves one inch apart, the fuse being elevated one inch above the base of block. In those tests in which the block was placed vertically, hydrostatic pressure lowered the fusing point, but when used horizontally the data may be regarded as the normal fusing points for these various wires.

The data of Table II will be clearly understood from the accompanying legends. One of our objects was to accurately measure the fusing times for abnormal currents. It is characteristic of all electro-thermal devices that they are sluggish in action. Cases may arise in practice where the insulation of wires

TABLE II.

FUSING TIMES IN SECONDS.

Amp.	I.	II.	III.	IV.	V.
15	84	75.8	—	—	—
20	36.6	35	—	—	—
25	19	17	60	45	195
30	12.8	10.8	33	26	41.6
35	9	7.6	20	16.4	30
40	7	5.8	14	12.6	25
45	5	4.8	10.4	9	17
50	4	4	9	7.4	13
55	3.6	3	6.6	5.8	—
60	3	2.6	5	5	8
65	2.8	2.2	4	4.6	—
70	2.8	1.8	3.6	3.6	5.4
75	2	1.6	3	3	—
80	1.8	—	—	2.6	4.8
85	—	—	—	2.2	—
90	—	—	—	2	3.6
95	—	—	—	1.8	—
100	—	—	—	1.6	3.2
105	—	—	—	1.4	—
110	—	—	—	1.2	2.8

I.—20 Amp. B. Horizontal 8 inches Mica supports each inch.
II.—20 Amp. B. Vertical 8 inches.
III.—20 Amp. A. Horizontal 8 inches Asbestos supports each inch.
IV.—20 Amp. A. Vertical 8 inches.
V.—25 Amp. A. Vertical 8 inches.

is forced to become a fuse competing with the metal supposed to protect the circuit. In all such cases it is only a question as to which shall yield the sooner. There is sufficient evidence in this table to explain why a fuse does not always protect an armature from burning out. The table becomes the more significant in this light when it is noticed that the data has been obtained by the use of an abnormally long fuse block. With the commercial block, the fusing times were increased many fold.

The results plotted in Fig. 2 are significant. The upper curve was obtained from three-ampere fuses in the covered block. The curve is here more sharply marked than in the case of the

same wire blown in an open block. This was found to be true for all sizes of wires tested in this manner, and indicates that a fuse is more sensitive in a covered than in an open block. In this case the shorter distance between the terminals raised the fusing point, and increased its inertia for higher currents.

It was considered desirable to obtain data which should exhibit the action of the fuse with the cooling effect of the terminals eliminated. To accomplish this, the fuses were blown in lengths of eight inches, with asbestos supports placed each inch of

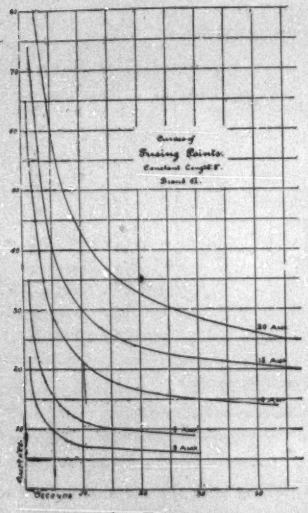

FIG. 3.

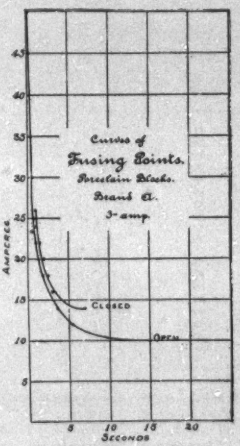

FIG. 2.

length, the block in all cases being horizontal. The supports practically prevented the breaking of the fuse from hydrostatic pressure. The results with A. and B. wires, and the German silver (18 per cent.), as well, are shown in Figs. 3–6. It was supposed though such curves are hyperbolic, that for abnormally high currents they would exhibit somewhat constant inertia times, due to the oxide coating and other mechanical causes. The results clearly confirmed this, the inertia time-constant in some cases amounting to two seconds.

The blowing of the fuse is not immediately an electrical act. The current fuses the metal, the cross-section is reduced at some point due to gravity, unequal expansion, or "sweating"; the heat in consequence intensifies at this point, and a globule falls, breaking the circuit and establishing an arc, which soon burns out a length of the fuse. This accounts for the sluggish action of such thermal cut-outs. An ideal fuse would be one that would act at approximately a constant time interval for all currents in excess of its normal. It would, in this respect closely resemble the action of an electro-magnetic cut-out. Its curve would be a straight line extending from its normal point, and slightly approaching the vertical axis for all abnormal currents, being thus identical with the curve of the electro-magnetic cut-outs. In practice the curves of all thermal cut-outs must be more or less modified hyperbolas. The ideal curve could only be attained were it possible to eliminate conduction and radiation losses. This is evidently the line to follow in designing a sensitive fusing block.

The curves in Figs. 3 and 4 clearly exhibit the relative sensitiveness of small and large fuse wires, the smaller diameters approaching more nearly the ideal condition. This is of great practical interest in guarding against excessive currents of short duration, such as motors are subject to when operated from street railway, and power circuits. In such cases a multiple fuse of four pieces of 5-ampere wire would prove from two to three times as sensitive as one piece of 20-ampere size. Such multiple fuses have been found by the writer to effectually prevent the belt slipping off the pulley of small dynamos under short-circuits. The sluggishness of large fuse wires may be due to the cooling of the outer layers which, with the oxide coating, prevent the fuse from breaking. It is evident that this effect would be less in small wires. For this reason a thin ribbon should prove more sensitive than a round wire.

These tests with long lengths of wire reveal some actions which may account for the lowering of the fusing point by use. In the A wires, with a current just below the fusing value, the wires were found to "sweat"; the oxide film broke in places and allowed the molten interior to ooze out. When the current was shut off the globules were drawn in, leaving the wire pitted. With the B fuses the metal was found to be remarkably plastic and free from the oxide film. These fuses sagged badly and twisted, showing a high coefficient of expansion. As a result they were drawn out and the cross-section reduced.

When used vertically, the metal flowed until a large globule formed, the rupture occurring just above this. In the case of

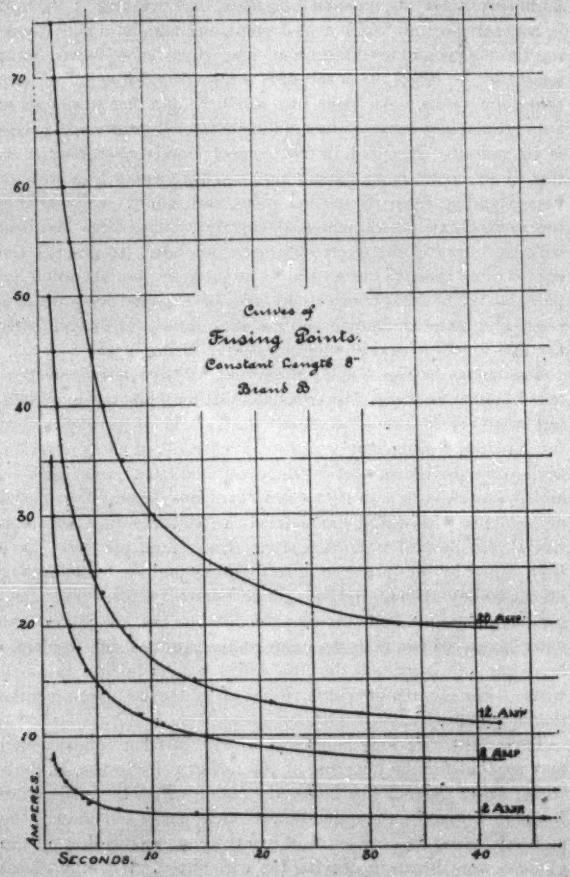

FIG. 4.

the German silver fuses the sweating resulted in partially breaking up the alloy, the zinc seeming to melt out from the nickel

and fusing with the copper, formed globules of brass. This was so marked that it would render such fuses too uncertain for use in all but the smallest diameters of wire.

A comparison of the 3-ampere curves in Figs. 2 and 3 shows the effect of shortening the fuse. The blowing current for 15 seconds of 6.3 amperes in the case of the short fuse in the open porcelain block, was raised to 10 amperes. Excepting the higher fusing points, the curve of the long fuse is the same as that for the shorter length. It is evident from such data that the usual

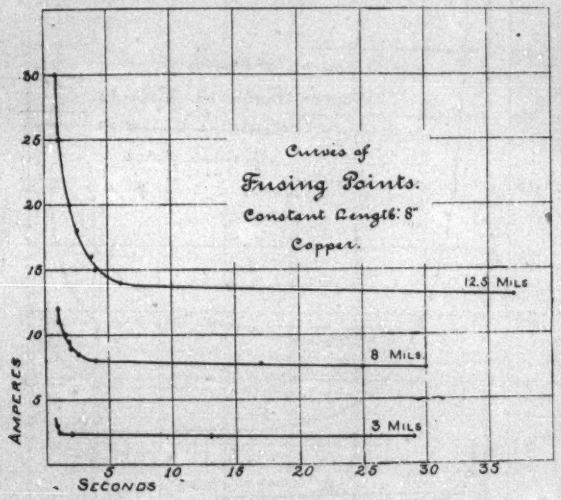

Fig. 5.

rating of fuse wires in ampere carrying capacity is practically valueless, and should be discontinued. The proper designation for such wires would be a table of carrying capacities for the lengths ordinarily employed.

The 10-ampere wire of Fig. 3 fused in 30 seconds at 15 amperes in an eight inch length; in a length of one-half inch in a covered block at 35 amperes, and in the open block, length seven-eighths inch, at 25 amperes. Accompanying each spool of the B wire was a stated carrying capacity for a given length, but this is not sufficient, since it furnishes no guide for other lengths.

Copper fuses have frequently been stated to be more prompt in action than the alloys usually employed. Compare the curve of the 12.5 mil copper wire (Fig. 5) with that of the 12-ampere wire in Fig. 4, and the increased sensibility of the copper fuse is apparent. The plastic condition of the ordinary fuse alloys ex-

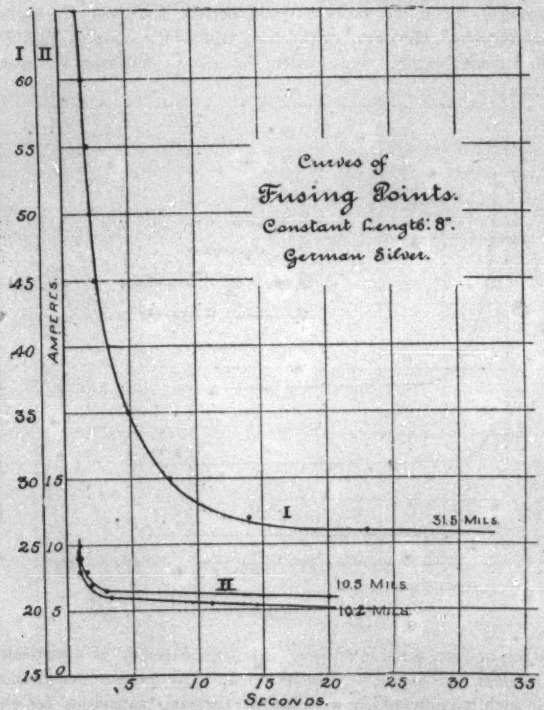

FIG. 6.

tends through a proportionately greater temperature range than the copper, resulting in a rounded curve. The copper fuses reached red and even white heat in these tests, while the other fuse wires scarcely reached a perceptible glow. This has a practical significance in selecting metals for fuse wires. Metals in

general, which can be worked at or near a white heat, will prove most sensitive, since a slight increase of heat will make them highly fluid, and rupture will promptly occur. The practice of using copper in street railway circuits for limit fuses seems justifiable. Whether the oxide film of copper fuses would prove progressive in formation, is a question which has not been definitely settled. A 3-mil copper wire, which fused at 2.2 amperes in 13 seconds, was fatigued at a red heat for eight minutes;

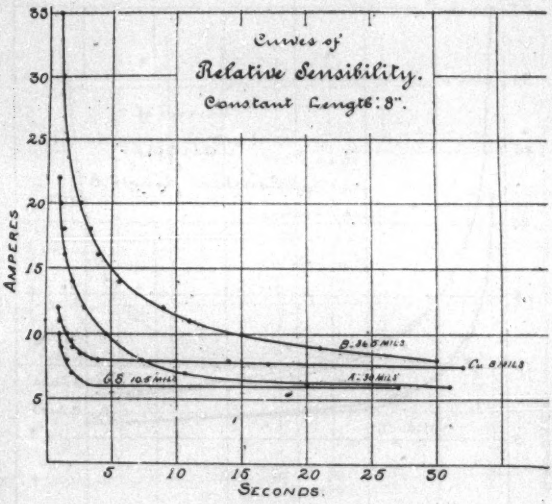

FIG. 7.

cooled and tested under the first condition, it fused at 2.2 amperes in 14 seconds.

The A fuses, cut from the ordinary lead-tin fuse wire, only worked at a bright red heat in very short lengths, such as ½ inch. This undoubtedly influenced the sharpness of the curve for the closed block in Fig. 2, and is a fact that seems to possess some practical importance. Our tests in general showed the desirability of working fuses at a red heat for normal maximum loads. But this is a question which must be eventually left with the underwriters.

Fig. 7 gives the relative sensibility for the different fuse metals tested, and the copper curve is clearly the best. German silver acts well in these wires, but for the larger sizes (Fig. 6) it offers no advantages, and deteriorates more rapidly than any wire tested. It is now in general use on telephone and similar circuits. The wire is about four inches in length and inclosed in a fibre tube. A number of such fuses, obtained from the Chicago

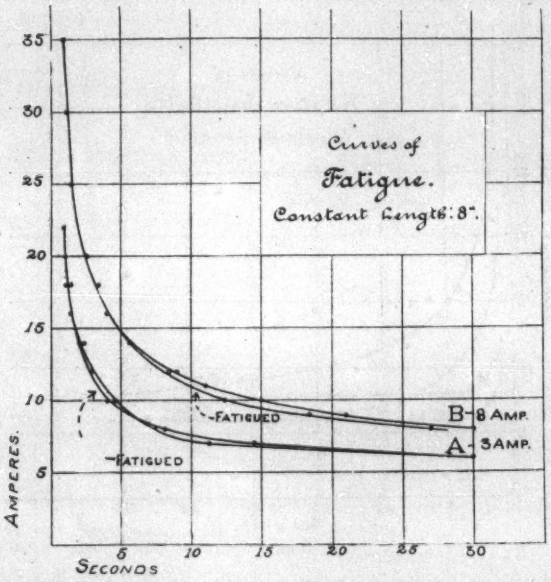

FIG. 8.

Telephone Company, were tested. They were rated for a carrying capacity of five amperes and fused in all cases within six amperes. A slight variation in fusing was no doubt due to the cooling effect of the tube in contact with the wire. Some such device as this, with copper wire for the fuse, would be most excellent for electric lighting and power circuits.

It was thought best to study the influence of "fatigue" on a wire. A special board was prepared with two rows of insulated

pins placed ten inches apart. A length of fuse wire was threaded back and forth over these, the wire being supported out of contact with the board. A current, just short of the fusing strength, was passed for seven hours. The results are plotted in Fig. 8. It will be noticed that the A fuses experienced a positive fatigue, the B wire a negative one. This is of importance in practice, and shows the superiority of the B wire, whose fusing point was lowered while the other was raised, due to a diminution of cross-section and absence of oxide film.

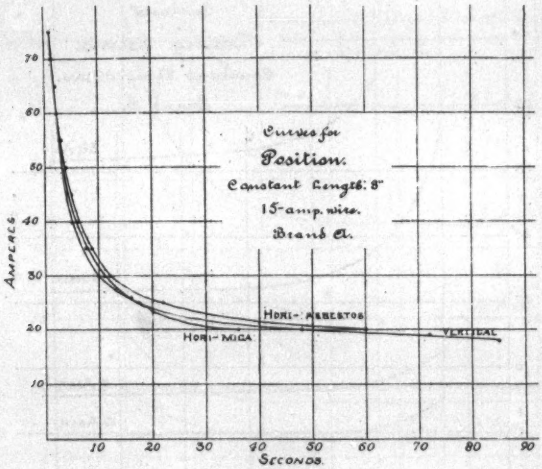

FIG. 9.

A great deal has been said about the influence of grease films on lead fuses. This point was also investigated. The grease was removed from the wires by immersion in KOH and NaOH with subsequent washing. In other cases the wire was cleaned by the use of fine sand-paper. The oxide film was also removed by immersion in nitric acid. Measurements showed that this treatment did not sensibly reduce the cross-section. When the oxide film was removed by either mechanical or chemical means it was noticed that a thicker coating formed at once, raising the fusing point. In short, these tests showed that nothing was

gained by cleaning the wires, but that the thin film of grease deposited during the drawing of the wire was rather an advantage. The wires were also coated with shellac, but without encouraging results. Some coating, not affected by heat, and which would reduce the radiation, would doubtless increase the stability and sensibility of fuse wires.

For the following tests an adjustable fuse block was constructed, on which the fuse was held about one inch above the base and

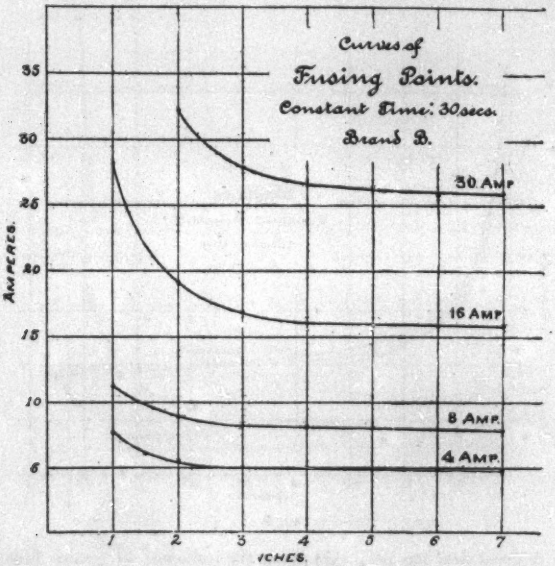

Fig. 10.

supported each inch by either thin asbestos or mica supports. In order to ascertain the influence of these supports, tests plotted in Fig. 9 were made. The influence of hydrostatic pressure is shown by the horizontal curve with the asbestos supports being higher than the vertical curve. The curve with mica supports is lower for the reason that the mica cut the softened wire.

A singular phenomenon was noticed with the A fuses blown horizontally in the eight-inch block. The arc would usually

occur at about the same place near the center of the fuse, and when the time was within six seconds, the entire fuse was shattered into approximately equal lengths, varying from $\frac{3}{8}$ inch to $\frac{1}{4}$ inch, depending upon the current employed. The length of these pieces varied inversely with the current strength. The uniformity of these results was noticeable throughout all our tests. The entire

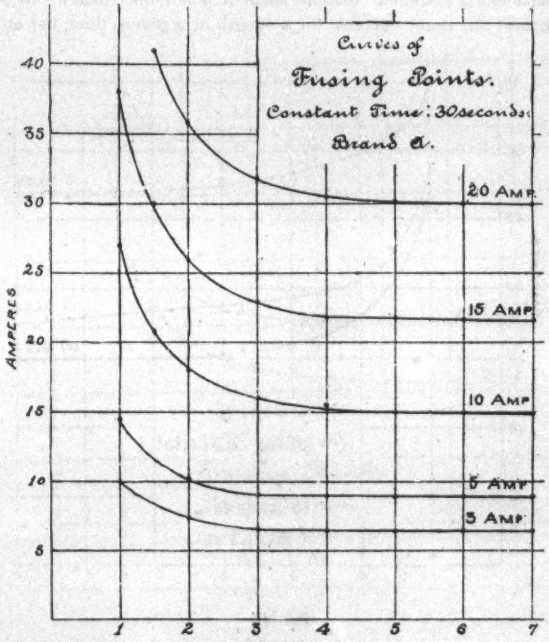

FIG 11.

fuse, to within a short distance of the terminal, seemed to explode into fragments simultaneously with the formation of the arc. This rhythmic action has been pointed out by the author for copper wire fused by lightning.[1] The ends of such pieces invariably showed a crystalline structure, indicating that the entire fuse was melted, and prevented from flowing by the oxide film.

1. *Electrical Engineer*, July 13, 1895, p. 38.

So much seems to depend on the cooling effect of the terminals, that it was determined to work this point out with great care. The terminals of the adjustable block were made of brass, and purposely made unusually massive. Care was also exercised to keep the terminal-contacts bright and clean. Constant fusing times were adopted, with varying lengths. This method of experiment is extremely tedious, since it is not only difficult to ascertain the exact current for a length in a given time, but any

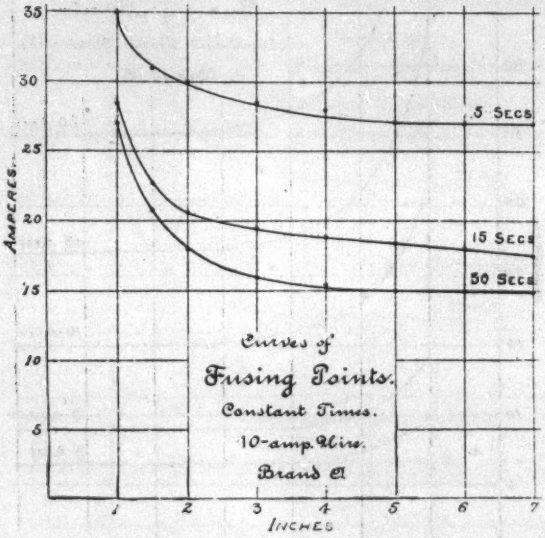

FIG. 12.

slight draught or variation in the current will produce a sensible modification in this time. Up to this point the current had been obtained from a 50-K. W. 110-volt D. C. dynamo, furnishing a sufficiently constant E.M.F. For the following tests a storage battery of 60, 180-ampere hour cells was employed. The result for a constant time of 30 seconds is shown in Figs. 10 and 11; and for constant times of 30, 15 and 5 seconds in Figs. 12 and 13. The relation between size of wire and length of fuse for maxi-

mum sensibility is shown by the curves of Figs. 10 and 11. The curves of Fig. 13 exhibit well the sluggish action of the fuse wire. For five seconds two inches is the critical length, while for a time of 30 seconds it is nearly five inches. Data for times longer than 30 seconds are not materially different from those at this period. For a given fuse, then, blown in a given time, there

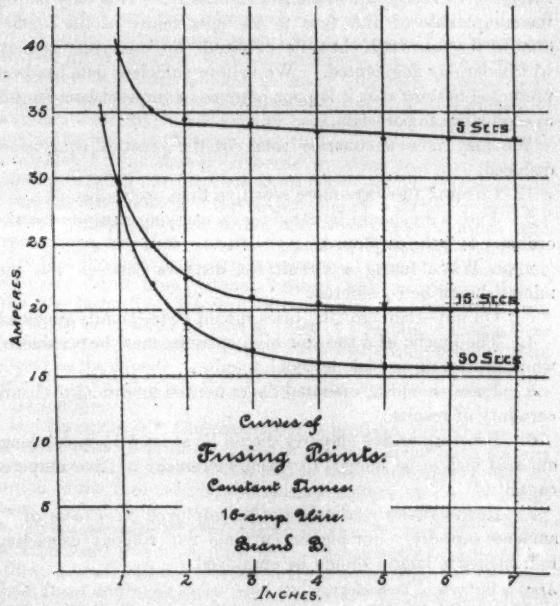

FIG. 13.

is a critical length. We are now in possession of full data for the complete discussion of this most important question.

If a fuse is to be employed for maximum sensibility at normal rating, the curves of Fig. 11 will enable the length to be determined by the location of the critical point in the curve, which is the point at which the cooling effect of the terminals becomes marked. For three- and five-ampere fuses, lengths of 2½ inches

should be employed; the 10- and 15-ampere fuses indicate a length of 3½ inches, the 20-ampere of 4 inches. Judged of by common practice these lengths seem excessive, but the data clearly indicate where practice might be corrected.

Comparing the curves in Fig. 2 with these, it is readily seen that the effect of the terminals is equivalent to shortening the time as in Fig. 13, and so increasing the carrying capacity. But these short lengths in no case fuse normally. It is only adding the complexity of the fuse to the uncertainty of the contact. Should the fuse itself become oxidized, the carrying capacity will be largely augmented. We believe sufficient data has been presented to show that it is poor practice to employ short lengths to economize in porcelain.

We may now summarize some of the practical conclusions deduced:

1. Covered fuses are more sensitive than open ones.

2. Fuse wire should be rated for its carrying capacity for the ordinary lengths employed.

2. (*a*) When fusing a circuit, the distance between the terminals should be considered.

3. On important circuits, fuses should be frequently renewed.

4. The inertia of a fuse for high currents must be considered when protecting special devices.

5. Fuses should be operated under normal conditions to ensure certainty of results.

6. Fuses up to five amperes should be at least 1½ inches long, one-half inch to be added for each increment of five amperes capacity.

7. Round fuse wire should not be employed in excess of 30 amperes capacity. For higher currents flat ribbons exceeding four inches in length should be employed.

Armour Institute of Technology,
Chicago, Oct. 1st, 1895.

Discussion.

The Chairman:—This paper, while dealing with a question that is by no means new, and should long ago have ceased to be a subject of discussion, is nevertheless one which is more constantly discussed and no more settled, than many of the problems which are far more difficult inherently. The physical conditions governing the fusion of a wire would appear to be very definite and easily determined. Certainly no one would imagine that

this subject would be one of the last to become definite from our point of view. But the fact remains that to-day fuse wires are by no means relied upon; indeed, the very term "fuse wire" is almost synonymous with unreliability. It certainly would not seem that this is a necessary condition. I think it is owing to the fact that the length of the wire, the terminals to which it is attached, and the question whether it is enclosed or open, and many other important conditions are entirely ignored. Under those circumstances no scientific accuracy can possibly be obtained. But provided each fuse wire were rated at a certain length and for use under certain conditions, I see no physical or other possibility of great variation between different fuses. Nevertheless the subject is so uncertain and so many engineers express their lack of confidence in the whole matter, that it is well worthy of consideration. But it has already been discussed quite recently by the INSTITUTE at Niagara, and the point was there brought out, which I think should be borne in mind to-night, that we must know what our fuses are expected to do. In other words, if one engineer intends a fuse to accomplish a certain result and another engineer another result, it obviously cannot fulfil both expectations, and that is another cause of difficulty. Some require that the fuse shall carry an abnormal current for a certain small interval of time without fusing. Others require that it shall fuse instantly. No fuse, of course, can do both. But even that could be covered by having fuses of a certain "inertia" as Professor Stine calls it, and other fuses that are supposed to yield as soon as the current reaches a definite excess. The subject is certainly one that is worthy of discussion and is now open for consideration.

DR. EMERY:—Mr. Chairman: It is probable that the principal electricians of prominent companies have given these matters very close study in some cases, and in this connection I call attention to the fuse used on the railway motors of the Westinghouse Company. If I recollect aright, they employ a fuse of No. 13 copper wire which is placed in a groove around a wooden block enclosed in a wood-lined box. Considerable length of fuse is thus secured, and it is protected from rapid radiation of heat. These fuses doubtless carry from 100 to 120 amperes and do not blow readily. One car will pull another on the track at a very slow speed and the fuse is rarely blown. When a fuse does blow it is with an explosion. I have used copper wire fuses frequently in experimenting with electric motors and found them very convenient and reliable.

MR. KENNELLY:—Mr. Chairman, the most important part of this important paper, is its end, where the conclusions appear, and I think, that at least in phraseology, if not in actual intention, some of these conclusions might be criticized; for example, the first conclusion, namely that covered fuses are more sensitive than open ones. Now I am not sure of the meaning that is intended

for the word sensitive in this case. If the word sensitive means that the fuses will ultimately melt within narrower limits of current strength than if the fuses are uncovered, I suppose we would all agree that this is correct. But if the word sensitive means sensitive in regard to time, or in regard to range of variation in which the duration of the current is included, I think the very opposite is true—that such fuses when covered are not more sensitive. The reason, of course, is clear. If you surround a fuse with some solid substance, if you place it in contact with some solid material, so soon as you heat the fuse, the fuse commences to impart heat to the solid material, and it cannot attain a melting temperature until a fairly large amount of heat has been so communicated, so that a considerable time must elapse before the temperature of the neighboring material has been so far raised as will permit the fuse to melt at its normal current. On the other hand, of course a fuse that is protected from drafts of air, or a fuse that is even protected by solid materials is more apt to be true to its rating, than one which is liable to be influenced by all the air currents in the neighborhood. The difficulty with fuses, as we all know, and as the Chairman has expressed it, is the fact that no two men usually employ fuses for the same purpose. In some cases they are wanted to blow, and blow promptly the moment that their fusing current is exceeded. In other cases they are not wanted to blow until a large excess of current strength is reached, and the two requirements are so opposed that it is not remarkable there has been a great diversity of practice and rating. The only way to obtain a unity of expression and a unity of rating, is to state precisely how the fuse is to be used, and curiously enough these two papers, which seem to be so remote from each other in application, although bound up in the same pamphlet form, have a very important bearing one upon the other; because we find that the environment in the case of the annealing of hard armor plates is just the very condition which enables the enormous current density of 40,000 amperes to the square inch to be employed, when under ordinary circumstances only a small fraction of that intensity could be employed in copper at the same temperature. Very often you will find that a fuse melts far below its rated capacity, simply because the copper terminals are not sufficiently large to carry away the heat, and the lead is blamed for what is entirely the fault of the copper connections.

I do not quite agree with Dr. Emery that copper wires make the best fuses. It is often very convenient to use a copper wire for a fuse, but the difficulty with a copper wire is frequently that if you wish to employ a sensitive fuse that shall melt at only a small margin above its rated capacity, you must operate that copper wire red hot under normal conditions in order that it shall melt at a reasonably small percentage above normal, and I think that has been the principal objection to copper wire fuses up to the present time.

Again, it surely is not necessary to employ fuses five inches in length, of five amperes on ordinary low circuits. If you can protect the fuse by putting it under cover, that is to say keep it from drafts of air and have specified or definite arrangements for clamping at the ends of it, you can use tin foil if necessary, for very weak currents, say below one ampere, and you can use fine wire for currents from one up to five amperes, without great difficulty. When you have various clamps and various conditions of air currents, then it is true that you must employ long fuses.

THE CHAIRMAN:—In the absence of the author I feel justified in making what appears to be an answer to Mr. Kennelly's first criticism in regard to Conclusion 1. As I understand him, he said that covered fuses signify those in contact with some material. I do not understand the sentence to mean that. It simply means enclosed fuses not necessarily in contact with, or perhaps not even within half an inch of any solid material.

MR. KENNELLY:—That would certainly overcome my objections.

MR. WOLCOTT:—I think that Conclusion 3 is quite an important one—that on important circuits fuses should be frequently renewed. If a fuse is run up to its rated capacity all the time, that certainly is very important. The metal will change, of course, that is shown in the paper here how the metal changes when the current is turned on. You certainly find that in ordinary fuses.

THE CHAIRMAN:—This matter is so fundamental in our profession that any progress that can be made with it is of considerable importance. It seems to me that the difficulty is largely dependent upon the fact that a certain spool of wire is sold as a ten ampere fuse, without specifying under what conditions it shall be used. I think that is about the sum and substance of the difficulty. But there may be more to it than that, and if so, we should hear from those who know further.

MR. R. T. LOZIER:—I think one of the most important points that Professor Stine has called attention to is Conclusion 3, that is to say frequently renewing the fuses. I know when I was connected with the Edison Company that the oxidation of the fuses in the street circuit boxes was rectified by changing the alloy to overcome that objection. I know that in practical experience that point of changing the fuses is one that is seldom recognized. It is one that I did not know of myself. I think that that one fact alone is a very important one to the profession.

THE CHAIRMAN:—That point, however, would relate rather to the question of fuses blowing sooner than they should, instead of not blowing when they should. It is those which do not blow when they are expected to, that have given fuses the reputation of unreliability. It is the fuses which carry two and three and four times their normal current that electrical engineers are suspicious of, and not the fuses which blow too easily, although of course the latter is not desirable. A fuse should not blow

below its rated current. At the same time it is not those which have given the bad reputation to fuses. I have heard hundreds of times of fuses carrying a multiple of the currents that they were intended for, and a large multiple at that.

MR. WOLCOTT:—I think the Chairman is entirely right in this matter. An instance of the trouble you generally find in fuses is this: If there is a fuse for a single light in the base of the lamp it sometimes will stand more than the plug that supplies the whole room, that is, the plug will blow and put out all the lights in the room instead of the single light fuse blowing.

THE CHAIRMAN:—Of course in safety devices, on general principles, it is much better to have them act too soon than too late as, for example, a safety valve.

MR. WM. STANLEY:—I know very little of the subject, but it seems to me that a perfect fuse would be one having a variable temperature coefficient, and consisting of a substance whose resistance should remain practically constant for the lower working temperatures, and should increase rapidly with higher temperatures produced by abnormal currents. I think that a copper wire itself possesses a very decided advantage in one way over the ordinary fuse wire. The process of passing from the solid to the fluid state is, in all metals, when arranged as they must be for fuses, a gradual process, whether it is because of some outside physical condition or not I do not know, but I have often noticed that portions of a fuse, especially of a strip, would be quite liquid while other portions would still remain hard, when there did not seem to be any good reason for such inequality due to inequality of area. A copper wire passes from the solid to the liquid state with an explosion. The ordinary fuse wire droops and slowly explodes, if I may use such a term, and while I have found in using fuses on transformers that a copper wire is the most reliable, I have also found that it is well to enclose it if one wants very reliable work—wants the fuse to be quite accurate—to enclose it in a glass tube filled with sand or brick dust or any gritty insulating material. After the breaking of a fuse so enclosed, one cannot find the constituent parts of it at all. It is as though it had evaporated.

THE CHAIRMAN:—Points of that kind are just what we require, I imagine. My experience in regard to copper fuses has been that they are more reliable than the ordinary fuse wires, although some high authorities say that is wrong—that we should use easily fusible alloys, but as a matter of fact I think that all practical men who have to use fuses in emergencies would rather depend upon a copper wire that they know something about than on a fuse wire. Alloys are of indefinite composition, whereas copper wire is of very definite composition. In other words, it is almost perfectly pure copper. Alloys may consist of any proportion of almost any metal. That might account, I think, for many of the great variations which occur in practice.

The idea of surrounding a copper wire with sand in a tube would seem to bring the conditions to a definite point, which is all, I think, that is needed. The conditions are certainly of the utmost simplicity, provided we can always get them the same. I cannot admit that this problem is a difficult one inherently. It is difficult only because on account of its extreme simplicity we have been careless about it and have not specified the conditions. We must specify how long the wire shall be, and where it must be placed, and, if necessary, we can have a dozen kinds of fuse wires of 10 amperes normal capacity to be used under different conditions. There is nothing very difficult about that or anything that differs very materially from the conditions in other questions. It is always necessary when we have definite scientific conditions to specify exactly what those conditions shall be, and that is what has been lacking in regard to fuses, and consequently their action has been a matter of guesswork and not of definite quantitative relations.

DR. EMERY:—Mr. Chairman: In line with the remarks of yourself and Mr. Stanley and in connection with my previous remarks, I call attention to the top of page 664 of the paper, which reads: "Copper fuses have frequently been stated to be more "prompt in action than the alloys usually employed. Comparing "the curve of 12.5 mil copper (Fig. 5) with that of the 12-ampere "wire in Fig. 4, and the increased sensibility of the copper fuse is "apparent." Examining the curve for copper referred to, it seems to be practically a straight and nearly horizontal line and changes suddenly as the current is increased, whereas the diagram for the other fuse, curves through a considerable range. This seems to show very clearly that the use of copper for fuses is advantageous. It will be observed that Mr. Stanley's method of putting the fuse in sand, is in line with that previously mentioned of winding copper wire around a block of wood, as considerable length is obtained in that way and the wire is also protected from radiation of heat, with the additional advantage that it is non-arcing. The principle appears to be well established that the part of the fuse which it is expected will blow, should be protected from radiation and contact with materials that will carry away the heat rapidly. Just before a copper wire fuse blows, the fused metal gathers in drops with smaller connecting necks so as to look like beads on a string, and this action probably continues until the fuse is disrupted explosively.

MR. J. W. HOWELL:—I do not know whether it is mentioned here or not, but one of the advantages of the copper fuse would be its rapid and known increase in resistance for temperature in which an alloy would be apt to be variable. I tried the experiment once of connecting a small piece of thin copper wire and German silver wire both the same size in series, and passing currents through them. With small currents the German silver wire would get much hotter than the copper, but as the current was increased, the increasing resistance of the copper made it very

much hotter and it fused first, although the German silver was very much hotter at the start.

MR. KENNELLY:—The question of copper versus alloy is a very interesting one, but simply bears out the importance of defining what a fuse is intended to do, and the limiting range of overload at which it is intended to melt. In some cases when a fuse is inserted to protect a circuit of given normal maximum current strength, the fuse should not melt unless three times that current strength passes through it. In other cases the fuse should melt when the current strength reaches twenty-five per cent. above the normal. The fuses which will meet these two distinct requirements, are necessarily different.

Lead alloy fuses can be made which will melt at, or even below, the temperature of 100° C. Consequently, under definite conditions, such fuses may readily be made sensitive in regard to action at excess of current, for their normal working temperatures will be but little in excess of the temperature of the air.

Copper wire fuses, on the other hand, melt at say 1050° C, which is a comparatively high temperature. Even granting the existence of a larger temperature coefficient of resistivity, the wire will have to be maintained at a comparatively high temperature, by the normal current strength, if it is required to melt at a small overload. In point of fact the temperature coefficient of copper does not seem to differ greatly near red heat from its value at the boiling point of water, and in some cases it would be necessary to keep the wire at 500° C, or about red heat under working currents in order to effect fusion at a comparatively small excess of current.

When, however, a large range of current excess can be permitted, the advantage of copper in the directions pointed out by the Chairman and by Dr. Emery, are, of course, undeniable.

THE CHAIRMAN:—There is this to be said, however, that copper for a given resistance has a much smaller surface than any alloy of that sort; consequently its temperature might be higher, and still the waste of energy might be the same on account of its smaller radiating and converting surface. These alloys have rather a high specific resistance. Copper has a minimum specific resistance and would have the minimum surface. That, I think, would make up for considerable difference in temperature. It has also been pointed out that since copper has a very high temperature of fusion, the danger of setting wire to adjacent bodies is much greater when it does melt. But the low melting point alloys produce an arc when they blow, and furthermore any fuse should be wound.

MR. HOWELL:—Mr. Chairman, in practice, what fuses are called upon to go at a slight increase of current over their normal working current?

THE CHAIRMAN:—There are two classes of fuses, but if I were asked to give examples of fuses that are called upon to yield at a certain definite current, I would be puzzled to name them.

MR. KENNELLY:—What I had in my mind was this: When you are working a motor, for example, there is a certain total amount of current that the machine will stand without injury, and when the current gets to that value you want a fuse that will certainly go. This limiting current strength may be two or three times the normal full load current strength. For such purposes a copper wire fuse may be suitable. But when you have a wire as, for example, a buried conductor with a sensitive insulating cover connected with a definite load of so many lamps for example, a comparatively small amount of current above the normal amount will heat that wire considerably, enough perhaps to damage the insulation, and you cannot afford to allow in such cases a very great range of current above the normal. There is a certain class of apparatus where you cannot allow very much range above the normal current. In telephony you have to put a delicate fuse in, arranged so as to just carry the normal current quite safely, but which with a little above that normal current will break. In such cases it seems to me a copper fuse is unsuited owing to the necessity for operating it at a comparatively very high temperature under normal conditions.

DR. F. B. CROCKER:—(Vice-President Hamblet in the chair.) As I seem to be taking the position of a debater rather than a presiding officer, I will ask Vice-President Hamblet to take the Chair because I cannot agree with Mr. Kennelly, and that would not be proper in a presiding officer. I fail in the first place to see any difference between a dynamo and a motor in that respect. Furthermore, I think that we are laboring under some misunderstanding in regard to what we mean in regard to overload. If we mean that the fuse will stand 25 per cent. increase for a few seconds, that is one question. If we mean that it shall not stand 25 per cent. increase for any appreciable time, that is another question. In other words, I understand Prof. Stine to mean when he speaks of inertia, that it takes an appreciable time for a fuse to give way even with an excessive current. Now I think that is a very desirable quality in a fuse—up to reasonable limits, of course. The motor, in that respect, is exactly like the fuse—in fact it is superior to the fuse. It will stand its overload for a greater length of time than the fuse will. The motor has a great capacity for heat since it contains a large weight of metal, but, of course, sparking is instantaneous in its effect; as soon as the excessive current occurs, if it be a direct current motor, it begins to spark. But it will stand that sparking a reasonable time without injury. I mean by reasonable time a few seconds. It will stand an excessive current for a few seconds without permanent injury, and that, of course, is the question which we are considering. So it seems to me that the fuse ought to coincide in its qualities and in its action with that which it is protecting, whatever that may be, and if this motor or whatever the device may be has a certain capacity for heat, and will stand this excessive

current for a few seconds without injury, the fuse should stand it also, for it certainly is very inconvenient to have fuses give way with 25 or even 50 per cent. increase in current if that increase of current is momentary, because it has not injured the motor and there is no reason why it is an advantage to have the fuse blow. On the other hand I can see a great many advantages in not having it blow, provided the excessive current is only momentary. So I think that the quality of inertia is just what a fuse should possess in most cases, and I agree with Mr. Howell that it is difficult to think of any case where we do not want that inertia, because all the apparatus which we use, have, if anything, more inertia than the fuse. I can think of only one exception to that, and that is the Cardew voltmeter. I have been trying to think of a possible example since Mr. Howell asked that question. In that instrument we have a hot wire, but we don't want to have it get too hot, and it will only stand a definite current without permanent injury. It has practically no heat "inertia," and the little fuse which it has should go at a definite current, and should not allow any increase above a definite figure. But that is the only example that I can think of where a fuse should not have inertia because it is the only case where the apparatus which it protects has no inertia. In any case the fuse should agree with that which it protects.

DR. EMERY:—We all like to keep in view some simple rule based on experimental investigations and in looking at the curves on page 663, Fig. 5, a very interesting relation is developed as to the proper size of copper wire to act as a fuse with definite amounts of current. It will be seen that approximately the amperes at the time the fuse blows are very nearly the same as the diameter of the wire in mils, showing that the resistance to fusion is proportioned to the radiating surface, as seems natural, and this is proportioned to the diameter. This simple rule may only apply to very small wires, as evidently the fuse used for railway motors above referred to, would not carry sufficient current if the rule applied to wires as large as those mentioned.

MR. STANLEY:—I might add just one word—it is this: That the use of sand in a tube containing a fuse wire, prevents arcing from the vapor of the metal. We are accustomed to put out an arc by blowing upon it and thus shattering it. In the case of the fuse surrounded by sand, the expansion of the gases due to the evaporation of the metal takes place through the spaces lying between the adjacent grains of sand, and the gases are shot through the sand and scattered in very much the same way as by blowing a breath of air across an arc. I have seen a fuse enclosed in sand which broke in carrying, I think, about 25 amperes at 4,000 volts, and which was not more than three or four inches in length.

[Adjourned.]

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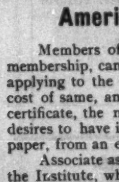

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